A. Riesel, J. Klawohn, N. Kathmann, T. Endrass

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ORIGINAL ARTICLE

Conflict monitoring and adaptation as reflected by N2 amplitude in obsessive–compulsive disorder

A. Riesel[1]*, J. Klawohn[1], N. Kathmann[1] and T. Endrass[1,2,3]

[1] *Department of Psychology, Humboldt-Universität zu Berlin, Berlin, Germany*
[2] *Department of Psychology, Institute of Clinical Psychology and Psychotherapy, Technische Universität Dresden, Dresden, Germany*
[3] *Institute of Psychology, Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany*

Background. Feelings of doubt and perseverative behaviours are key symptoms of obsessive–compulsive disorder (OCD) and have been linked to hyperactive error and conflict signals in the brain. While enhanced neural correlates of error monitoring have been robustly shown, far less is known about conflict processing and adaptation in OCD.

Method. We examined event-related potentials during conflict processing in 70 patients with OCD and 70 matched healthy comparison participants, focusing on the stimulus-locked N2 elicited in a flanker task. Conflict adaptation was evaluated by analysing sequential adjustments in N2 and behaviour, i.e. current conflict effects as a function of preceding conflict.

Results. Patients with OCD showed enhanced N2 amplitudes compared with healthy controls. Further, patients showed stronger conflict adaptation effects on reaction times and N2 amplitude. Thus, the effect of previous compatibility was larger in patients than in healthy participants as indicated by greater N2 adjustments in change trials (i.e. iC, cI). As a result of stronger conflict adaptation in patients, N2 amplitudes were comparable between groups in incompatible trials following incompatible trials.

Conclusions. Larger N2 amplitudes and greater conflict adaptation in OCD point to enhanced conflict monitoring leading to increased recruitment of cognitive control in patients. This was most pronounced in change trials and was associated with stronger conflict adjustment in N2 and behaviour. Thus, hyperactive conflict monitoring in OCD may be beneficial in situations that require a high amount of control to resolve conflict, but may also reflect an effortful process that is linked to distress and symptoms of OCD.

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Key words: Conflict adaptation, conflict monitoring, error-related negativity, N2, obsessive–compulsive disorder.

Introduction

The contents of obsessional thoughts, like 'did I turn off the stove?' or 'are my hands clean?', are also experienced by 80–90% of non-clinical subjects (e.g. Rachman & de Silva, 1978; Crye *et al.* 2010). However, if these thoughts are frequently experienced and accompanied by distress, anxiety or compulsive behaviours, the criteria for an obsessive–compulsive disorder (OCD) may be fulfilled (American Psychiatric Association, 2013). Obsessions and compulsions are often related to potential harm or disastrous consequences of errors, such as burning the house or infecting oneself or others. Thus, it has been proposed that key symptoms of OCD like the feeling of incompleteness, doubt regarding the correctness of own actions and repetitive behaviours may result from hyperactive monitoring of behaviour for potential errors and conflicts (Pitman, 1987). This notion motivated studies using event-related potentials (ERPs) on neural correlates of performance monitoring and conflict adaptation in OCD.

A number of studies investigated performance monitoring in OCD with tasks eliciting response conflict. Evidence for enhanced monitoring of behavioural responses has been shown by larger amplitudes for the response-related error-related negativity (ERN; Falkenstein *et al.* 1991; Gehring *et al.* 1995) and correct-related negativity (CRN; Ford, 1999) in OCD (Gehring *et al.* 2000; Endrass *et al.* 2008; Hajcak *et al.* 2008; Stern *et al.* 2010; Riesel *et al.* 2011, 2014, 2015*a*; Mathews *et al.* 2012; Endrass & Ullsperger, 2014). However, results with regard to the processing of stimulus conflict and subsequent adjustment are less consistent (Stern & Taylor, 2014). The processing of stimulus conflict has been related to the N2 component of the ERP (Folstein & Van Petten, 2008). While some studies show enhanced N2 amplitudes in OCD

* Address for correspondence: A. Riesel, Department of Psychology, Humboldt-Universität zu Berlin, Rudower Chaussee 18, 12489 Berlin, Germany.
(Email: anja.riesel@hu-berlin.de)

(Towey *et al.* 1993; Ruchsow *et al.* 2007; Ciesielski *et al.* 2011), others report evidence for a reduction (Morault *et al.* 1997; Kim *et al.* 2007; Keskin-Ergen *et al.* 2014) or no difference in N2 amplitude (Herrmann *et al.* 2003; Keskin-Ergen *et al.* 2014). ERN and N2 are both characterized by a fronto-central topography and are assumed to share a common neural substrate, the posterior medial frontal cortex (van Veen & Carter, 2002; Ridderinkhof *et al.* 2004; Iannaccone *et al.* 2015). Furthermore, both components are suggested to signal the need for an increase of cognitive control to avoid failure (Botvinick *et al.* 2001; Yeung *et al.* 2004; Ullsperger *et al.* 2014; Iannaccone *et al.* 2015). Thus, the discrepancies with regard to enhanced ERN but inconsistent findings in N2 in OCD call for further investigation. Task characteristics and motivational factors have been shown to modulate aberrant error processing in OCD patients (Gründler *et al.* 2009; Endrass *et al.* 2010; Riesel *et al.* 2015*b*) and may represent a potential explanation for variability in N2 results.

Another potential moderator of results is differences in the ability to flexibly adapt conflict or error monitoring to external requirements. Endrass *et al.* (2010) showed that healthy controls flexibly regulate error monitoring in accordance to experimental requirements (i.e. up-regulate in conditions of heightened error relevance, down-regulate under standard conditions), whereas OCD patients show enhanced error monitoring independently of situational demands. Flexibility in conflict monitoring is usually investigated by examining sequential conflict effects especially with regard to beneficial effects of conflict on subsequent adaptation (Gratton *et al.* 1992). Several studies found that healthy controls show reduced conflict effects in behavioural and electrophysiological markers after incompatible trials, which is thought to reflect an adaptation related to compensatory adjustment in cognitive control (Botvinick *et al.* 2001; Kerns, 2006; Larson *et al.* 2014). One previous study found reduced conflict adaptation in paediatric patients with OCD (Liu *et al.* 2012).

The aim of the present study was to examine behavioural and electrophysiological correlates of conflict monitoring and adaptation in a large sample of adult patients with OCD. Based on OCD symptoms such as doubt, repetitive behaviours and uncertainty, we would expect enhanced responses to conflict (i.e. enhanced N2 amplitudes) in OCD patients. This is further supported by the outlined similarities between ERN and N2 and the well-documented enhancement of ERN amplitude in OCD (Endrass & Ullsperger, 2014). However, based on previous results showing reduced conflict adaptation in paediatric OCD (Liu *et al.* 2012) and an inverse relationship between N2 and CRN in healthy participants (Grützmann *et al.* 2014), it is also possible that enhanced ERN and CRN amplitudes in OCD reflect a compensatory process for reduced conflict monitoring at stimulus processing, which would suggest reduced N2 amplitudes in OCD. Furthermore, the flexibility and adaptability of conflict monitoring are studied by sequential trial-by-trial conflict adaptation effects. We assume that patients with OCD show an inflexible monitoring of conflicts as it has been shown for paediatric OCD patients (Liu *et al.* 2012) and as it has been suggested for errors (Endrass *et al.* 2010).

Method

Participants

A total of 70 patients with OCD (38 females) and 70 healthy comparison participants (38 females) were included in the current study (Table 1). Data on error monitoring of 132 of these participants have been published in a previous study (Riesel *et al.* 2014). All patients were recruited from the out-patient unit of the Department of Psychology at Humboldt University, Berlin, and were in the diagnostic phase before starting cognitive–behavioural therapy. Patients were diagnosed by trained clinicians using the Structured Clinical Interview for DSM-IV (SCID; First *et al.* 1996) and fulfilled criteria for OCD as a primary diagnosis. Healthy comparison participants were recruited from the community through advertisement. Both groups were matched with regard to age and level of education. All participants were aged between 18 and 65 years, had normal or corrected-to-normal vision, and reported no history of head trauma or neurological disease. Exclusion criteria for patients were a lifetime diagnosis of psychotic or substance-related disorders; additional exclusion criteria for healthy controls were psychopharmacological treatment, psychotherapy and any present or past mental disorders as assessed with the SCID (First *et al.* 1996). A total of 34 patients (48.6%) had one to three current co-morbid diagnoses, such as affective disorders (major depression $n = 25$, dysthymia $n = 2$), anxiety disorders (social phobia $n = 15$, panic disorder $n = 4$, generalized anxiety disorder $n = 3$, specific phobia $n = 6$), eating disorders (bulimia $n = 2$), somatoform disorders (hypochondrias $n = 1$), Tourette syndrome ($n = 1$) and personality disorders (obsessive–compulsive $n = 11$, avoidant $n = 3$, dependent $n = 2$, histrionic $n = 2$). Of the patients, 32 (45.7%) were currently receiving psychotropic medication (serotonin reuptake inhibitors $n = 26$, tricyclic antidepressants $n = 6$), which had been stable for at least 4 weeks before study participation. Participants received written and verbal information about the study, and gave written informed consent. Study procedures were in accordance

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Table 1. *Demographic, clinical and performance measures of patients with OCD and healthy control participants*

	Healthy control participants ($n = 70$)	OCD patients ($n = 70$)	t (df = 138)	p
Demographic				
Age, years	38.6 (12.3)	35.2 (10.9)	1.73	0.09
Verbal IQ	108.7 (10.1)	108.9 (9.5)	0.40	0.89
Clinical				
OCI-R	5.9 (5.0)	28.2 (13.5)	12.92	<0.001
BDI-II	3.9 (5.1)	15.1 (11.2)	7.62	<0.001
Y-BOCS	–	21.8 (5.9)	–	–
MADRS	–	7.8 (6.8)	–	–
Performance				
Error rates, %				
cC	0.16 (0.80)	0.05 (0.17)	−1.19	0.24
iC	0.50 (1.72)	0.26 (0.57)	−1.10	0.27
cI	7.42 (3.62)	6.34 (2.38)	−2.07	<0.05
iI	1.67 (1.25)	1.12 (0.83)	−3.05	<0.01
Reaction times of correct reactions, ms				
cC	294 (47)	280 (35)	−1.90	0.06
iC	321 (48)	310 (35)	−1.51	0.13
cI	409 (46)	395 (35)	−2.06	<0.05
iI	395 (48)	376 (35)	−2.64	<0.01
Number of segments for correct reactions retained after artifact rejection				
cC	72.9 (10.6)	70.3 (13.1)	−1.29	0.199
iC	144.4 (21.2)	140.1 (24.8)	−1.09	0.274
cI	91.5 (24.2)	92.1 (24.4)	0.15	0.884
iI	60.7 (12.4)	62.1 (12.8)	0.67	0.504

Data are given as mean (standard deviation).

OCD, Obsessive–compulsive disorder; df, degrees of freedom; IQ, intelligence quotient; OCI-R, Obsessive–Compulsive Inventory-Revised; BDI-II, Beck Depression Inventory-II; YBOCS, Yale–Brown Obsessive Compulsive Scale; MADRS, Montgomery–Åsberg Depression Rating Scale; cC, compatible trials preceded by a compatible trial; iC, compatible trials preceded by an incompatible trial; cI, incompatible trial preceded by a compatible trial; iI, incompatible trial preceded by an incompatible trial.

with the ethical guidelines of the Declaration of Helsinki, as approved by the local ethics committee.

Measures

Participants completed the Beck Depression Inventory-II (BDI-II; Steer *et al.* 1997; Hautzinger *et al.* 2006) as well as the Obsessive–Compulsive Inventory-Revised (OCI-R; Foa *et al.* 2002; Gonner *et al.* 2008), and a vocabulary test measuring verbal intelligence (Schmidt & Metzler, 1992). Severity of obsessive–compulsive symptoms was additionally rated by trained clinicians in patients with the Yale–Brown Obsessive Compulsive Scale (Goodman *et al.* 1989; Hand & Büttner-Westphal, 1991). Depressive symptoms were rated through the Montgomery–Åsberg Depression Rating Scale (Montgomery & Åsberg, 1979; Neumann & Schulte, 1989).

Task

An arrowhead flanker task (Kopp *et al.* 1996) was administered using Presentation software (Neurobehavioral Systems, Inc., USA). On each trial, five vertically aligned arrows were presented and participants were instructed to respond with their index fingers in accordance with the direction of the central arrow. Responses were collected from response buttons with a 1000 Hz sampling rate. The four flanker stimuli were presented for 110 ms and pointed to the left or to the right. Then, flanker and target stimuli were presented simultaneously for 50 ms, followed by an inter-trial interval that varied randomly between 900 and 1500 ms. Half of the trials were compatible (i.e. flanker and target point in the same direction), and half were incompatible (i.e. flanker and target point in the opposite direction). Stimulus compatibility and direction varied pseudo-randomly across trials. Identical

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stimulus repetitions were omitted since conflict adaptation effects are sensitive to repetition priming (e.g. Mayr *et al.* 2003; Clayson & Larson, 2011; Schmidt & De Houwer, 2011). In all, 500 trials including 20 practice trials were presented. Short breaks and performance-based feedback were given every 60 trials. If error rates in one block were above 20%, participants were instructed to respond more accurately. When error rate was below 10%, participants were asked to respond faster. If error rates ranged between 10 and 20%, participants were reminded to respond both quickly and accurately. The duration of the experiment was about 25 min.

Electroencephalogram (EEG) recording, data reduction and analysis

The EEG was recorded from 65 electrodes with Cz as recording reference. Electrodes were mounted on an electrode cap with equidistant electrode positions (EASYCAP GmbH, Germany). External electrodes were placed below the left and right eyes, on the nasion, neck and below T1 (ground). All impedances were kept below 5 kΩ. The EEG was sampled at 500 Hz and amplified with a band pass filter of 0.01–100 Hz. Eye movement artifacts were corrected using the multiple source eye correction method (Berg & Scherg, 1994) implemented in BESA 5.2 (Brain Electrical Source Analysis, MEGIS Software GmbH, Germany). A digital low-pass filter set at 40 Hz and a notch filter at 50 Hz were applied to the raw data. Stimulus-locked epochs with a duration of 800 ms including a 200 ms pre-stimulus interval were extracted. Epochs containing a voltage step of more than 50 μV between consecutive sample points or a voltage difference of 200 μV of any two sample points within the epoch were excluded from averaging. The pre-stimulus interval −200 to −100 ms served as baseline. Before computing individual and grand averages for the N2, we calculated the current source density of the signal (Perrin *et al.* 1989) to enhance local electrical activities and reduce the effect of distal activities (volume conduction). N2 amplitudes were quantified at electrode FCz as the difference between the most negative peak occurring between 200 and 400 ms following the stimulus and the preceding positive peak (150–300 ms).

Statistical analyses were conducted using SPSS (version 21.0; USA). *t* Tests were used to assess group differences in demographic and symptom measures. To analyse conflict adaptation in N2 and behavioural measures, the Gratton effect (Gratton *et al.* 1992) was evaluated by analysing current conflict as a function of preceding conflict. The following trial combinations are possible: compatible trials either preceded by a compatible (cC) or an incompatible trial (iC) and incompatible trials either preceded by a compatible (cI) or an incompatible trial (iI). Electrophysiological and behavioural data were analysed with repeated-measures analysis of variance using group (OCD patients *v.* comparison participants) as the between-subject factor and compatibility of the current (compatible *v.* incompatible) and preceding trial (compatible *v.* incompatible) as within-subject factors. Further, the overall conflict adaptation effect for N2 and behaviour was calculated using the formula: (cI – cC) – (iI – iC) (Nieuwenhuis *et al.* 2006; Clayson & Larson, 2012). Error and post-error trials were excluded from ERP and behavioural analyses to avoid interference with error-related adaptation effects. The number of artifact-free trials in the four conditions are reported in Table 1 and did not differ between groups. For the OCD group, control analyses with medication status and co-morbidity as between-subject factors were conducted. For all analysis of variance results the effect size η_P^2 was reported. For group comparisons Cohen's *d* and 95% confidence intervals (CIs) for Cohen's *d* were additionally reported. Correlation coefficients (Pearson *r*) were used to examine associations between symptom severity and conflict adaptation in N2 as well as behaviour.

Results

Demographic and clinical characteristics

Table 1 presents demographic, clinical and behavioural measures as well as statistical information for the *t* test comparing groups. Groups did not differ with regard to age, verbal intelligence quotient and gender. OCD patients scored higher on self-reported symptom severity for both OCI-R and BDI-II.

Behavioural data

Error rates as well as reaction time on correct trials as a function of the compatibility of the current and preceding trials are shown in Table 1 and Fig. 1. Overall, OCD patients committed fewer errors than healthy comparison participants as reflected in a main effect of group ($F_{1,138} = 6.47$, $p < 0.05$, $\eta_P^2 = 0.05$, $d = 0.43$, 95% CI 0.09–0.76). Error rates were higher for incompatible than compatible trials ($F_{1,138} = 586.99$, $p < 0.001$, $\eta_P^2 = 0.81$). An interaction between group and current trial type emerged ($F_{1,138} = 3.89$, $p = 0.05$, $\eta_P^2 = 0.03$). A group difference in error rates was only observed in incompatible trials ($t_{138} = 2.53$, $p < 0.05$, $d = 0.43$, 95% CI 0.09–0.76), but not in compatible trials ($t_{138} = 1.14$, $p = 0.26$, $d = 0.19$, 95% CI −0.14 to 0.52). An interaction between preceding and current trial compatibility was found for error rates ($F_{1,138} = 632.10$, $p < 0.001$, $\eta_P^2 = 0.82$). Error rates were higher for cI than iI trials ($t_{139} =$

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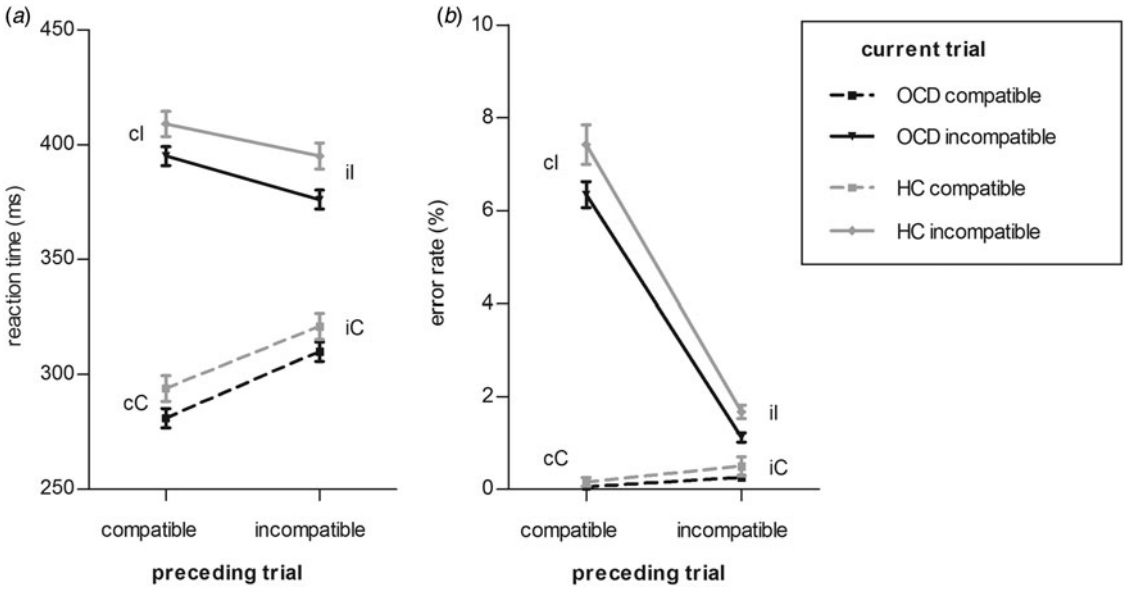

Fig. 1. Reaction times (*a*) and error rates (*b*) for healthy comparison (HC) participants and patients with obsessive–compulsive disorder (OCD) as a function of the compatibility of the current and preceding trial type. Values are means, with standard errors represented by vertical bars. cI, Incompatible trial preceded by a compatible trial; iI, incompatible trial preceded by an incompatible trial; cC, compatible trials preceded by a compatible trial; iC, compatible trials preceded by an incompatible trial.

25.19, $p < 0.001$), suggesting that conflict associated with the preceding trial improves conflict resolution in the current trial. The interaction of current trial compatibility, preceding trial compatibility and group was not significant ($F_{1,138} = 1.99$, $p = 0.16$, $\eta_P^2 = 0.01$). In accordance, the conflict adaptation score for error rates indicated an adaptation present in healthy controls (mean = 6.10, S.D. = 3.22) and patients (mean = 5.45, S.D. = 2.10), while no significant group difference was found ($t_{138} = 1.41$, $p = 0.16$, $d = 0.25$, 95% CI −0.07 to 0.59).

Responses for correct trials were significantly shorter in patients than in controls ($F_{1,138} = 4.39$, $p < 0.05$, $\eta_P^2 = 0.03$, $d = 0.36$, 95% CI 0.02–0.69). Overall, reaction times were longer for incompatible compared with compatible trials ($F_{1,138} = 3847.43$, $p < 0.001$, $\eta_P^2 = 0.97$), and longer in trials following incompatible trials ($F_{1,138} = 95.98$, $p < 0.001$, $\eta_P^2 = 0.41$). A significant interaction between preceding and current trial type compatibility was observed ($F_{1,138} = 1078.45$, $p < 0.001$, $\eta_P^2 = 0.89$). The effect of current compatibility on reactions times was larger in trials preceded by compatible trials (mean = 115 ms, S.D. = 21) compared with trials preceded by incompatible trials (mean = 70 ms, S.D. = 18, $t_{139} = 32.21$, $p < 0.001$). A significant interaction of current trial compatibility, previous trial compatibility and group was found ($F_{1,138} = 6.45$, $p < 0.05$, $\eta_P^2 = 0.05$). This interaction suggests that the reduction of the compatibility effect following incompatible trails was more pronounced in patients with OCD (mean = 66, S.D. = 18) than in healthy comparison participants (mean = 74, S.D. = 18, $t_{138} = 2.64$, $p < 0.05$, $d = 0.45$, 95% CI 0.11–0.78). The reaction time difference following compatible trials did not differ between groups ($t_{138} = 0.32$, $p = 0.75$, $d = 0.05$, 95% CI −0.28 to 0.39). These results suggest greater conflict adaptation in OCD patients, which was also reflected in a higher conflict adaptation score in reaction times for patients (mean = 48.15, S.D. = 17.09) compared with healthy participants (mean = 41.24, S.D. = 15.04, $t_{138} = 2.54$, $p < 0.05$, $d = 0.43$, 95% CI 0.09–0.76).

Electrophysiological data

Grand average waveforms for N2 as well as topographies are presented in Fig. 2. Patients with OCD show higher (i.e. more negative) N2 amplitudes than healthy controls ($F_{1,138} = 7.10$, $p < 0.01$, $\eta_P^2 = 0.05$, $d = 0.45$, 95% CI 0.11–0.79). The main effect of current trial compatibility was not significant ($F_{1,138} = 3.34$, $p = 0.07$, $\eta_P^2 = 0.02$), but a significant effect of preceding trial compatibility was found ($F_{1,138} = 8.43$, $p < 0.01$, $\eta_P^2 = 0.06$). Further, the interaction of preceding and current trial compatibility was significant ($F_{1,138} = 44.33$, $p < 0.001$, $\eta_P^2 = 0.24$). Importantly, a significant interaction of both factors with group was observed ($F_{1,138} = 6.76$, $p < 0.01$, $\eta_P^2 = 0.05$) (see Fig. 2*c*). A significant reduction in N2 amplitude in iI trials compared with cI trials (i.e. Gratton effect) was found in healthy comparison participants ($t_{69} = 2.83$, $p < 0.01$) and in patients with OCD ($t_{69} = 6.54$, $p < 0.001$). This reduction was larger for patients with OCD (mean = 6.94, S.D. = 8.89) than for healthy controls (mean = 2.73, S.D. = 8.09, $t_{138} = 2.93$, $p < 0.01$, $d = 0.50$,

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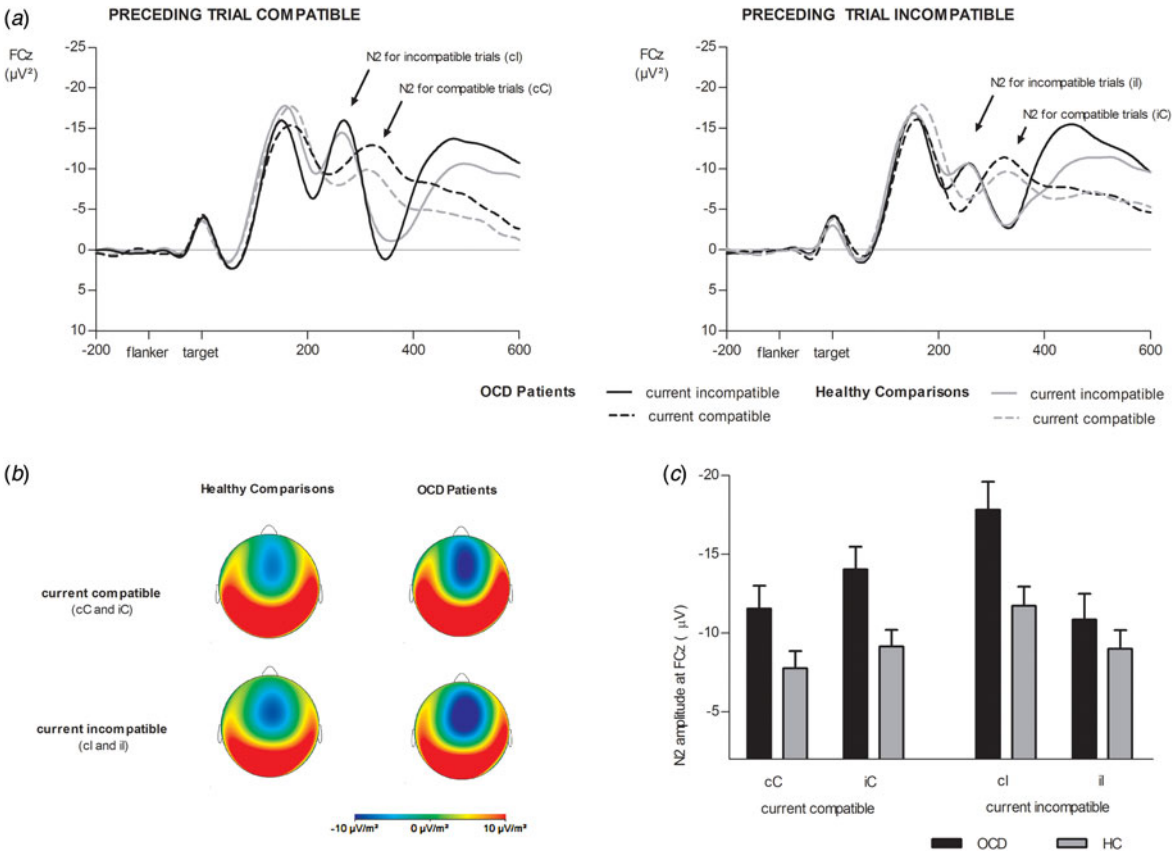

Fig. 2. (*a*) Grand average waveforms at electrode site FCz of stimulus-locked N2 in healthy comparison (HC) participants and patients with obsessive–compulsive disorder (OCD) for current incompatible (solid lines) and compatible trials (dashed lines) that are preceded by compatible (left subfigure) or incompatible trials (right subfigure). (*b*) Topographies (current source density) of N2 in the time window from 250 to 350 ms after stimulus presentation. For interpretation of the colour scale of the topographies in this figure, the reader is referred to the web version of this article. (*c*) N2 amplitudes at electrode site FCz in HC participants and patients with OCD for current compatible trials and incompatible trials as a function of preceding conflict. Values are means, with standard errors represented by vertical bars.

95% CI 0.16–0.83). As a result of stronger conflict adaptation in patients with OCD, group differences disappeared in iI trials ($t_{138} = 0.92$, $p = 0.36$, $d = 0.16$, 95% CI −0.18 to 0.49), whereas N2 amplitudes were larger in OCD patients in all other conditions (cI, $t_{138} = 2.81$, $p < 0.01$, $d = 0.48$, 95% CI 0.14–0.81; iC, $t_{138} = 2.72$, $p < 0.01$, $d = 0.46$, 95% CI 0.12–0.79; cC, $t_{138} = 2.07$, $p < 0.05$, $d = 0.35$, 95% CI 0.02–0.68). An influence of previous trial compatibility on current compatible trials was found for OCD patients, who showed larger N2 in iC trials compared with cC trials ($t_{138} = 2.29$, $p < 0.05$), whereas healthy comparison participants did not show a significant difference ($t_{138} = 1.55$, $p = 0.13$). The overall conflict adaptation score also indicated stronger conflict adaptation in N2 amplitude for OCD patients (mean = −9.44, S.D. = 13.12) compared with healthy comparison participants (mean = −4.14, S.D. = 10.91, $t_{138} = 2.6$, $p < 0.01$, $d = 0.44$, 95% CI 0.10–0.78). The larger score in OCD patients reflected a stronger effect of preceding conflict on N2 amplitude, i.e. a larger difference in N2 after compatible trials (cI, cC) than after incompatible trials (iI, iC), reflecting the beneficial effects of conflict resolution in the previous trial.

Additional analyses were calculated using medication status and co-morbidity as between-subject factors in the patient group. Neither medication status ($F_{1,67} = 0.06$, $p = 0.95$, $\eta^2_P = 0.002$), nor co-morbidity ($F_{1,67} = 1.14$, $p = 0.29$, $\eta^2_P = 0.02$), significantly influenced the observed pattern of results in patients.

Correlational analyses

No significant correlations of the conflict adaptation scores for N2, error rates, and reaction times with clinical measures (OCI-R and BDI-II) in OCD patients were observed (all $p > 0.26$, $r < 0.11$). In healthy comparison participants, a significant correlation of the conflict adaptation score for the N2 with the BDI-II emerged ($r = -0.24$, $p < 0.05$), indicating higher conflict adaptation in the N2 (i.e. more negative values) with higher BDI-II scores. However, this correlation was

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driven by two participants with the highest BDI-II scores; after exclusion of them the correlation was no longer significant ($r = -0.15$, $p = 0.21$).

Discussion

The current study showed enhanced conflict monitoring in OCD during stimulus processing as reflected by larger N2 amplitudes. Further, OCD patients showed greater conflict adaptation in N2 amplitudes and reaction times. Our results are consistent with studies showing an increase of N2 amplitudes in OCD (Towey *et al.* 1993; Ruchsow *et al.* 2007; Ciesielski *et al.* 2011) and, more broadly, in individuals with high trait anxiety or behavioural inhibition (Dennis & Chen, 2009; Leue *et al.* 2012, 2014), traits that are transdiagnostically associated with anxiety disorders and OCD. However, several studies in OCD did not report differences in N2 amplitude (Herrmann *et al.* 2003; Keskin-Ergen *et al.* 2014) or even reported an N2 reduction (Morault *et al.* 1997; Kim *et al.* 2007; Keskin-Ergen *et al.* 2014). Similarly, a study examining patients with generalized anxiety disorder (Larson *et al.* 2013), a disorder that shares key symptoms with OCD such as worry and overestimation of threat, found evidence for reduced principal-component N2 amplitudes and conflict adaptation in N2 but not at the behavioural level. Overall, this variability in findings across studies needs further clarification and future studies should examine potential moderators such as task characteristics, data analysis techniques and heterogeneity in symptoms. For example, Larson *et al.* (2013) only found group differences in principal-component N2, but not in original N2 amplitudes suggesting that different functional aspects and sources are captured in ERP N2 and principal component analysis-derived factors. Further, co-morbidity (e.g. Weinberg *et al.* 2012), differences in symptoms between generalized anxiety disorder and OCD as well as heterogeneity within OCD symptoms (Mataix-Cols *et al.* 2005) are potential confounds that could lead to discrepant findings. With regard to task effects, previous studies mostly used Go/NoGo tasks to analyse conflict monitoring in OCD (Herrmann *et al.* 2003; Kim *et al.* 2007; Ruchsow *et al.* 2007; Keskin-Ergen *et al.* 2014). Go/NoGo tasks require a high degree of response inhibition, which is proposed to be dysfunctional in OCD (Chamberlain *et al.* 2005, 2007; Penades *et al.* 2007; Woolley *et al.* 2008). To avoid the potential influences of response inhibition, the flanker task was recommended for the analysis of conflict monitoring and adaptation (Larson *et al.* 2014). Further, most studies focused on high conflict trials (e.g. Ciesielski *et al.* 2011). The present results suggest that alterations in conflict monitoring in OCD depend on current and previous conflict and that sequential conflict adaptation is altered in OCD. Altogether, the present results indicate that OCD patients show hyperactive conflict monitoring as implied by OCD symptoms such as worry about potential harm and errors and intolerance of uncertainty. Together with the robust finding of enhanced ERN amplitudes in OCD (e.g. Endrass & Ullsperger, 2014) this strengthens hyperactive monitoring as a core dysfunction in OCD.

The examination of sequential trial-by-trial modulations in conflict monitoring allows us to further disentangle the observed hyperactivity in conflict monitoring in OCD. Patients with OCD seem to be more sensitive to newly occurring conflicts than healthy participants (i.e. cI). Moreover, they also show dysfunctional hyperactive monitoring in non-conflicting situations (i.e. cC and iC), where there is no demand for higher recruitment of cognitive control. This might be seen as an unnecessary effort, but could as well be connected to symptoms of distress and doubt (Klawohn *et al.* 2014), or a high need to avoid potential harm. Further, this parallels and extends results by Endrass *et al.* (2010) indicating that hyperactive error monitoring in OCD cannot be further up-regulated by external demands (Endrass *et al.* 2010). Similar to our results, group differences emerged in conditions in which it is not particularly adaptive to strongly monitor one's own actions and in which healthy participants down-regulated their monitoring (Endrass *et al.* 2010). In summary, our results suggest that OCD is characterized by hyperactive monitoring that seems to operate more independently of the actual monitoring demands, since it is observed not only in errors and high-conflict trials, but also in compatible trials and correct responses low in conflict.

Beyond this general hyperactivity, OCD patients showed greater trial-by-trial adaptation in response to conflict as reflected in behaviour as well as N2 amplitude. A larger increase (i.e. up-regulation) was observed in compatible trials that follow incompatible ones and a larger decrease (i.e. down-regulation) in incompatible trials that are preceded by incompatible trials. When it is adaptive to recruit more control and invest more resources (i.e. in iI trials), similar monitoring was observed in patients and controls. Hence, in these trials OCD patients even benefit from their generally overactive monitoring, in that they show a stronger conflict adaptation, which leads to a normalization in N2 in iI trials and is accompanied by a more successful behavioural conflict adaptation. These results fit well to conflict monitoring accounts, which state that enhanced conflict processing leads to a stronger recruitment of cognitive control and subsequently to

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a more effective conflict resolution (Kerns *et al.* 2004; Kerns, 2006; Carter & van Veen, 2007). Thus, the enhanced processing of conflict in OCD seems to be associated with a stronger allocation of control and resources to the next trial as reflected by a greater conflict adaptation in N2 and reaction times. Our results are consistent with Ciesielski *et al.* (2011) who also concluded that OCD patients show enhanced adaptive top-down control and linked that to prefrontal and dorsal anterior cingulate networks. However, our results are in contrast to behavioural results reported by Liu *et al.* (2012) showing reduced post-conflict adaptation in paediatric OCD patients. Although only a direct comparison of same-age groups would allow clarification, possible explanations may relate to differences in task difficulty or patient populations. Liu *et al.* (2012) used a complex multi-source interference task (Bush & Shin, 2006) that elicits high levels of conflict and longer reaction times were observed than in the current task, possibly diminishing the currently observed greater conflict adjustment effects. Alternatively, conflict processing and adjustment may differ between patients with childhood *v.* adult onset of OCD similar to results for the ERN that suggest that the relationship between the ERN and anxiety changes as a function of age (Meyer *et al.* 2011). In conclusion, our results suggest that hyperactive conflict monitoring in adult patients with OCD seemed to be beneficial in situations that include a high amount of conflict and require the recruitment of control to resolve conflict. However, this is associated with a stronger monitoring in non-conflicting situations which may be related to more effort and higher employment of resources. This parallels symptoms of OCD such as compulsions that often aim to reduce rare negative consequences and may even reduce risk to some extent (e.g. washing hands reduces the risk for infections), but at the costs of daily functioning and enhanced distress.

Limitations of the current study are that patients taking psychotropic medication and with co-morbidities were included. However, *post-hoc* analyses showed that results were not affected by medication or co-morbidity. Moreover, the large sample size and the inclusion of a naturalistic, heterogeneous patient sample allows the analysis of co-morbidities and medication effects with sufficient power and, thus, represents a strength of this study. Another important avenue for future studies should be the analysis of lateralized readiness potentials in the context of conflict adaptation in clinical groups. This would allow us to further disentangle effects of conflict processing from those of motor preparation and motor inhibition, processes that might add to differences in conflict adaptation in patients with OCD as well.

Overall, the current study supports that OCD patients are characterized by a hyperactive monitoring system that is not adapted (i.e. down-regulated) in unambiguous, non-conflicting situations. This may be related to OCD symptoms such as doubt and the higher need to avoid harm and control actions and thoughts. The present results further suggest benefits in conflicting situations that occur in the context of conflict as reflected by an enhanced conflict adaptation in OCD patients, both in EEG and behaviour. This stronger conflict adaptation has been linked to an enhanced recruitment of top-down cognitive control (Kerns *et al.* 2004; Kerns, 2006; Carter & van Veen, 2007; Ciesielski *et al.* 2011) triggered by an enhanced conflict monitoring.

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References

American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders*, fifth edn. American Psychiatric Association: Washington, DC.

Berg P, Scherg M (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalography and Clinical Neurophysiology* **90**, 229–241.

Botvinick MM, Braver TS, Barch DM, Carter CS, Cohen JD (2001). Conflict monitoring and cognitive control. *Psychological Review* **108**, 624–652.

Bush G, Shin LM (2006). The Multi-Source Interference Task: an fMRI task that reliably activates the cingulo-frontal-parietal cognitive/attention network. *Nature Protocols* **1**, 308–313.

Carter CS, van Veen V (2007). Anterior cingulate cortex and conflict detection: an update of theory and data. *Cognitive, Affective, and Behavioral Neuroscience* **7**, 367–379.

Chamberlain SR, Blackwell AD, Fineberg NA, Robbins TW, Sahakian BJ (2005). The neuropsychology of obsessive compulsive disorder: the importance of failures in cognitive and behavioural inhibition as candidate endophenotypic markers. *Neuroscience and Biobehavioral Reviews* **29**, 399–419.

Chamberlain SR, Fineberg NA, Menzies LA, Blackwell AD, Bullmore ET, Robbins TW, Sahakian BJ (2007). Impaired cognitive flexibility and motor inhibition in unaffected first-degree relatives of patients with obsessive–compulsive disorder. *American Journal of Psychiatry* **164**, 335–338.

Ciesielski KT, Rowland LM, Harris RJ, Kerwin AA, Reeve A, Knight JE (2011). Increased anterior brain activation to correct responses on high-conflict Stroop task in obsessive–compulsive disorder. *Clinical Neurophysiology* **122**, 107–113.

Clayson PE, Larson MJ (2011). Effects of repetition priming on electrophysiological and behavioral indices of conflict

https://doi.org/10.1017/S0033291716003597

adaptation and cognitive control. *Psychophysiology* **48**, 1621–1630.

Clayson PE, Larson MJ (2012). Cognitive performance and electrophysiological indices of cognitive control: a validation study of conflict adaptation. *Psychophysiology* **49**, 627–637.

Crye J, Laskey B, Cartwright-Hatton S (2010). Non-clinical obsessions in a young adolescent population: frequency and association with metacognitive variables. *Psychology and Psychotherapy – Theory Research and Practice* **83**, 15–26.

Dennis TA, Chen CC (2009). Trait anxiety and conflict monitoring following threat: an ERP study. *Psychophysiology* **46**, 122–131.

Endrass T, Klawohn J, Schuster F, Kathmann N (2008). Overactive performance monitoring in obsessive–compulsive disorder: ERP evidence from correct and erroneous reactions. *Neuropsychologia* **46**, 1877–1887.

Endrass T, Schuermann B, Kaufmann C, Spielberg R, Kniesche R, Kathmann N (2010). Performance monitoring and error significance in patients with obsessive–compulsive disorder. *Biological Psychology* **84**, 257–263.

Endrass T, Ullsperger M (2014). Specificity of performance monitoring changes in obsessive–compulsive disorder. *Neuroscience and Biobehavioral Reviews* **46**, 124–138.

Falkenstein M, Hohnsbein J, Hoormann J, Blanke L (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology* **78**, 447–455.

First MB, Gibbon M, Spitzer RL, Williams JB (1996). *Structured Clinical Interview for DSM-IV Axis I Disorders: Non-Patient Edition* (*SCID-I, version 2.0*). Biometrics Research, New York State Psychiatric Institute: New York.

Foa E, Huppert J, Leiberg S, Langner R, Kichic R, Hajcak G, Salkovskis P (2002). The Obsessive–Compulsive Inventory: development and validation of a short version. *Psychological Assessment* **14**, 485–496.

Folstein JR, Van Petten C, (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology* **45**, 152–170.

Ford JM (1999). Schizophrenia: the broken P300 and beyond. *Psychophysiology* **36**, 667–682.

Gehring WJ, Himle J, Nisenson LG (2000). Action-monitoring dysfunction in obsessive–compulsive disorder. *Psychological Science* **11**, 1–6.

Gehring WJ, Coles MG, Meyer DE, Donchin E (1995). A brain potential manifestation of error-related processing. *Electroencephalography and Clinical Neurophysiology* **44**, 261–272.

Gonner S, Leonhart R, Ecker W (2008). The Obsessive–Compulsive Inventory-Revised (OCI-R): validation of the German version in a sample of patients with OCD, anxiety disorders, and depressive disorders. *Journal of Anxiety Disorders* **22**, 734–749.

Goodman WK, Price LH, Rasmussen SA, Mazure C, Fleischmann RL, Hill CL, Heninger GR, Charney DS (1989). The Yale–Brown Obsessive Compulsive Scale. I. Development, use, and reliability. *Archives of General Psychiatry* **46**, 1006–1011.

Gratton G, Coles MG, Donchin E (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology: General* **121**, 480–506.

Gründler TO, Cavanagh JF, Figueroa CM, Frank MJ, Allen JJ (2009). Task-related dissociation in ERN amplitude as a function of obsessive–compulsive symptoms. *Neuropsychologia* **47**, 1978–1987.

Grützmann R, Riesel A, Klawohn J, Kathmann N, Endrass T (2014). Complementary modulation of N2 and CRN by conflict frequency. *Psychophysiology* **51**, 761–772.

Hajcak G, Franklin ME, Foa EB, Simons RF (2008). Increased error-related brain activity in pediatric obsessive–compulsive disorder before and after treatment. *American Journal of Psychiatry* **165**, 116–123.

Hand I, Büttner-Westphal H (1991). Die Yale–Brown Obsessive Compulsive Scale (Y-BOCS): ein halbstrukturiertes Interview zur Beurteilung des Schweregrades von Denk- und Handlungszwängen [The Yale–Brown Obsessive Compulsive Scale (Y-BOCS): a semi-structured interview for assessing severity of compulsive cognitions and behaviour. *Verhaltenstherapie* **1**, 223–225.

Hautzinger M, Keller F, Kühner C (2006). *Beck Depressions-Inventar* (*BDI-II*) [Beck Depression Inventory (*BDI-II*)]. Harcourt Test Services: Frankfurt.

Herrmann MJ, Jacob C, Unterecker S, Fallgatter AJ (2003). Reduced response-inhibition in obsessive–compulsive disorder measured with topographic evoked potential mapping. *Psychiatry Research* **120**, 265–271.

Iannaccone R, Hauser TU, Staempfli P, Walitza S, Brandeis D, Brem S (2015). Conflict monitoring and error processing: new insights from simultaneous EEG-fMRI. *NeuroImage* **105**, 395–407.

Kerns JG (2006). Anterior cingulate and prefrontal cortex activity in an fMRI study of trial-to-trial adjustments on the Simon task. *NeuroImage* **33**, 399–405.

Kerns JG, Cohen JD, MacDonald III AW, Cho RY, Stenger VA, Carter CS (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science* **303**, 1023.

Keskin-Ergen Y, Tükel R, Aslantaş-Ertekin B, Ertekin E, Oflaz S, Devrim-Üçok M (2014). N2 and P3 potentials in early-onset and late-onset patients with obsessive–compulsive disorder. *Depression and Anxiety* **31**, 997–1006.

Kim MS, Kim YY, Yoo SY, Kwon JS (2007). Electrophysiological correlates of behavioral response inhibition in patients with obsessive–compulsive disorder. *Depression and Anxiety* **24**, 22–31.

Klawohn J, Riesel A, Grutzmann R, Kathmann N, Endrass T (2014). Performance monitoring in obsessive–compulsive disorder: a temporo-spatial principal component analysis. *Cognitive, Affective, and Behavioral Neuroscience* **14**, 983–995.

Kopp B, Rist F, Mattler U (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology* **33**, 282–294.

Larson MJ, Clawson A, Clayson PE, Baldwin SA (2013). Cognitive conflict adaptation in generalized anxiety disorder. *Biological Psychology* **94**, 408–418.

Larson MJ, Clayson PE, Clawson A (2014). Making sense of all the conflict: a theoretical review and critique of conflict-related ERPs. *International Journal of Psychophysiology* **93**, 283–297.

Leue A, Lange S, Beauducel A (2012). Modulation of the conflict monitoring intensity: the role of aversive

https://doi.org/10.1017/S0033291716003597

reinforcement, cognitive demand, and trait-BIS. *Cognitive, Affective, and Behavioral Neuroscience* **12**, 287–307.

Leue A, Weber B, Beauducel A (2014). How do working-memory-related demand, reasoning ability and aversive reinforcement modulate conflict monitoring? *Frontiers in Human Neuroscience* **8**, 210.

Liu Y, Gehring WJ, Weissman DH, Taylor SF, Fitzgerald KD (2012). Trial-by-trial adjustments of cognitive control following errors and response conflict are altered in pediatric obsessive compulsive disorder. *Frontiers in Psychiatry* **3**, 41.

Mataix-Cols D, Rosario-Campos MC, Leckman JF (2005). A multidimensional model of obsessive–compulsive disorder. *American Journal of Psychiatry* **162**, 228–238.

Mathews CA, Perez VB, Delucchi KL, Mathalon DH (2012). Error-related negativity in individuals with obsessive–compulsive symptoms: toward an understanding of hoarding behaviors. *Biological Psychology* **89**, 487–494.

Meyer A, Weinberg A, Klein D, Hajcak G (2011). The development of the error-related negativity (ERN) and its relationship with anxiety: evidence from 8 to 13 year-olds. *Developmental Cognitive Neuroscience* **2**, 152–161.

Mayr U, Awh E, Laurey P (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience* **6**, 450–452.

Montgomery SA, Åsberg M (1979). A new depression scale designed to be sensitive to change. *British Journal of Psychiatry* **134**, 382–389.

Morault PM, Bourgeois M, Laville J, Bensch C, Paty J (1997). Psychophysiological and clinical value of event-related potentials in obsessive–compulsive disorder. *Biological Psychiatry* **42**, 46–56.

Neumann N, Schulte R (1989). *MADR-Skala zur psychometrischen Beurteilung depressiver Symptome (MADRS) [MADR Scale for Psychometric Assessment of Depressive Symptoms (MADRS)]*. Perimed: Erlangen.

Nieuwenhuis S, Stins JF, Posthuma D, Polderman TJ, Boomsma DI, de Geus EJ (2006). Accounting for sequential trial effects in the flanker task: conflict adaptation or associative priming? *Memory and Cognition* **34**, 1260–1272.

Penades R, Catalan R, Rubia K, Andres S, Salamero M, Gasto C (2007). Impaired response inhibition in obsessive compulsive disorder. *European Psychiatry* **22**, 404–410.

Perrin F, Pernier J, Bertrand O, Echallier JF (1989). Spherical splines for scalp potential and current-density mapping. *Electroencephalography and Clinical Neurophysiology* **72**, 184–187.

Pitman RK (1987). A cybernetic model of obsessive–compulsive psychopathology. *Comprehensive Psychiatry* **28**, 334–343.

Rachman S, de Silva P (1978). Abnormal and normal obsessions. *Behaviour Research and Therapy* **16**, 233–248.

Ridderinkhof KR, Ullsperger M, Crone EA, Nieuwenhuis S (2004). The role of the medial frontal cortex in cognitive control. *Science* **306**, 443.

Riesel A, Endrass T, Auerbach LA, Kathmann N (2015*a*). Overactive performance monitoring as an endophenotype for obsessive–compulsive disorder: evidence from a treatment study. *American Journal of Psychiatry* **172**, 665–673.

Riesel A, Endrass T, Kaufmann C, Kathmann N (2011). Overactive error-related brain activity as a candidate endophenotype for obsessive–compulsive disorder: evidence from unaffected first-degree relatives. *American Journal of Psychiatry* **168**, 317–324.

Riesel A, Kathmann N, Endrass T (2014). Overactive performance monitoring in obsessive–compulsive disorder is independent of symptom expression. *European Archives of Psychiatry and Clinical Neuroscience* **264**, 707–717.

Riesel A, Richter A, Kaufmann C, Kathmann N, Endrass T (2015*b*). Performance monitoring in obsessive–compulsive undergraduates: effects of task difficulty. *Brain and Cognition* **98**, 35–42.

Ruchsow M, Reuter K, Hermle L, Ebert D, Kiefer M, Falkenstein M (2007). Executive control in obsessive–compulsive disorder: event-related potentials in a Go/Nogo task. *Journal of Neural Transmission* **114**, 1595–1601.

Schmidt JR, De Houwer J (2011). Now you see it, now you don't: controlling for contingencies and stimulus repetitions eliminates the Gratton effect. *Acta Psychologica* **138**, 176–186.

Schmidt KH, Metzler P (1992). *WST. Wortschatztest*. Beltz Test GmbH: Göttingen.

Steer RA, Ball R, Ranieri WF, Beck AT (1997). Further evidence for the construct validity of the Beck Depression Inventory-II with psychiatric outpatients. *Psychological Reports* **80**, 443–446.

Stern ER, Liu Y, Gehring WJ, Lister JJ, Yin G, Zhang J, Fitzgerald KD, Himle JA, Abelson JL, Taylor SF (2010). Chronic medication does not affect hyperactive error responses in obsessive–compulsive disorder. *Psychophysiology* **47**, 913–920.

Stern ER, Taylor SF (2014). Cognitive neuroscience of obsessive–compulsive disorder. *Psychiatric Clinics of North America* **37**, 337–352.

Towey J, Bruder G, Tenke C, Leite P, DeCaria C, Friedman D, Hollander E (1993). Event-related potential and clinical correlates of neurodysfunction in obsessive–compulsive disorder. *Psychiatry Research* **49**, 167–181.

Ullsperger M, Fischer A, Nigbur R, Endrass T (2014). Neural mechanisms and temporal dynamics of performance monitoring. *Trends in Cognitive Sciences* **18**, 259–267.

van Veen V, Carter CS (2002). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiology and Behavior* **77**, 477–482.

Weinberg A, Klein DN, Hajcak G (2012). Increased error-related brain activity distinguishes generalized anxiety disorder with and without comorbid major depressive disorder. *Journal of Abnormal Psychology* **121**, 885–896.

Woolley J, Heyman I, Brammer M, Frampton I, McGuire PK, Rubia K (2008). Brain activation in paediatric obsessive compulsive disorder during tasks of inhibitory control. *British Journal of Psychiatry* **192**, 25–31.

Yeung N, Botvinick MM, Cohen JD (2004). The neural basis of error detection: conflict monitoring and the error-related negativity. *Psychological Review* **111**, 931–959.

https://doi.org/10.1017/S0033291716003597